Tribo-evaluation of Aluminium Based Metal Matrix Composites Used for Automobile Brake Pad Applications

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Abstract

Al- Based metal matrix composites used for automobile brake pad applications are fabricated through P/M route using 'Preform powder forging' technology. Dry sliding wear behavior of Al-MMC based brake pads against cast iron disc is studied as per ECR R-90 regulation on Krauss machine tribo-tester. It was observed that the Al- based brake pads posses lower wear rate, same order of Coefficient of friction as in resin bonded brake pads, while the temperature rise is one third as compared with resin bonded brake pads. The vibration and judder of Al based brake pads is slightly higher in comparison to resin based brake pad. Thus the present study reveals that the development of Al-based metal matrix friction composites has a great potential in making automobile brake pads and may replace the existing resin bonded brake pads in varieties of applications. The fracture surface of the brake pad is studied under SEM and it was found that the constituents are uniformly distributed in friction layers as well as in backing plate.

Keywords

Al-MMC; Automobile Brake Pad; Resin-Bonded Brake Pads; Dry Sliding Wear; Krauss Machine Tribo-tester

Introduction

Friction materials for automotive brake systems contain metallic ingredients to improve their wear resistance, thermal diffusivity, and strength. Various metals such as copper, iron, aluminum, steel, brass, and bronze have been used in the form of fibers or powder particles in the friction material. The type, morphology, and hardness of the metallic ingredients affect the coefficient of friction and wear of friction materials [1]. Currently, steel fibers are used in the friction material industry since steel fibers provide good wear resistance and maintain friction effectiveness at elevated temperature (fade resistance with fast recovery) [2]. However, steel fibers are induced excessive disk wear and large disk thickness variation (DTV), thereby brake vibration or judder is generated during braking. The aggressiveness of steel fibers against a brake rotor appears due to their high hardness and the metallic adhesion between steel and gray cast iron. Copper or copper alloys are mainly added to improve the thermal diffusivity at the friction interface. Copper is also known to sustain the level of the coefficient of friction (COF) at elevated temperatures by producing copper oxides at the friction interface. Therefore, copper or copper alloys are added to control the friction level while avoiding the aggressiveness against counter surface. Aluminum fibers are added to the friction material when aluminum metal matrix composite (Al-MMC) brake rotors are used [3, 4]. Information concerning the particular role of Al fibers on friction characteristics is seldom found in the literature. The coefficient of friction and wear of metal to metal contact has been studied extensively and plenty of information is available in tribology literature [5, 6]. The siding character of pure metals is based on an adhesion mechanism at the friction interface [5, 7, 8]. Due to the influences of other ingredients in the composite, the friction coefficient obtained during pure metal to metal contact is differed from that of a composite. The role of metal fibers in friction materials on braking performance has not been yet widely reported, it may be partly due to proprietary reasons. In this study, friction characteristics of three Al powder based composites namely FAl01and FAl02 are investigated using Krauss rig friction tester. Friction tests are carried at ambient temperature.

Experimental Details

Two Aluminium based friction composites which are

designated as FA-101 and FA-102 were formulated.

TABLE 1 SPECIFICATION OF CONSTITUENTS

SAMPLES	CONSTITUENTS, WT.%					
	AL	SIC	SB2S3	BASO4	ZINC	GRAPHITE
	(100μM)	(200μM)	(40μM)	(40μM)	(50μM)	(50μM)
FA-101	78.35	8.45	2	3	3	9.55
FA-102	76.01	6.45	2	3	3	7.54

Preform Powder Forging Technology

This technology involves four processes namely (a) Blending/Mixing of powder mixture for back plate (b) Blending/Mixing of powder mixture for friction material preparation, (c) Cold compacting and (d) Hot forging .

Blending/Mixing of Powder Mixture for Back Plate

70 wt% Al powder (100μm) and 30% fine SiC (50 μm) powder are thoroughly blended (manually) and then this powder mixture is mechanically alloyed in a pot mill for about 2-3 hrs using ceramic balls (10 mm dia.) in the ratio of 1:5 (weight of powder mixture / weight of ceramic ball).

Blending/Mixing of Powder Mixture for Friction Material Preparation

The ceramic SiC (coarse: 200 μm powder, filler $BaSO_4$ (40μm), solid lubricants Sb_2S_3 (40μm) and graphite powder (45 μm) in fixed amount (wt. %) are mixed manually for one hr. and then this mixture is mechanically alloyed in pot mill for 6 hrs. using hardened steel balls (dia. - 4.5mm) in the ratio of 1:5 (weight of powder mixture / weight of steel balls). The powder mix is prepared for cold compacting.

Cold Compacting

Preform is prepared from the above stated powder mix by cold compacting which consists of i) Powder filling in the die, ii) Compacting of powder using friction screw press and iii) Ejection of the preform. To avoid the rubbing between die and punch during compaction and easy withdrawal of the preform, the die and punch surfaces are coated with suspension of fine graphite (45μm) and ethanol. This makes it possible to produce a net-shaped preform and eliminate the probability of die-punch damaging. Preform is prepared for final processing namely hot forging.

Hot forging

Powder preform is heated to 450 °C and held at this temperature for one hour in muffle furnace (soaking), and then it is transferred into a stationary die and hot forged at this temperature by a movable punch. For lubrication of die and easy withdrawal of the product, the die and punch surfaces are coated with suspension of graphite (45μm) and ethanol. This makes it possible to produce a net-shaped forged product having high density and high strength. Three different composites namely FAl01 and FAl02 are fabricated.

Testing Procedure

The dry wear tests are conducted for one hour using a Krauss type RWDC 100C (450 V/50 Hz) machine. The disc is connected through an interchangeable flange to a shaft that generated a moment of inertia of 2.5 kgm^2. Two brake pads with a total area of 32×10–4 m^2 are press-fitted into a pressure-actuated sliding caliper assembly. Pads are forced against opposite sides of the rotor disc at a mean contact radius of 101 mm. The load on the pads is adjusted to keep the applied contact pressure at 1.82 MPa. A load cell, mounted on the frame carrying the caliper pad assembly, is used to measure the friction force. The nominal surface temperature of the pad and disc is estimated from a thermocouple held lightly against the circumference of the disc. The friction force and temperature rise on the disc surface are recorded after every cycle of braking in a synchronized manner. In order to evaluate the dry wear tests characteristics of the friction materials, Economic Commission for Europe (ECE R-90) regulation for replaceable brake lining is adopted. The disc rotation rate is fixed at 660 rpm to conform to that test. Wear loss of the composites is calculated using weight change materials/thickness of brake pad in term of mm.

Table 2 and Table 3 shows the specification of grey cast iron rotor inertia wheel and Krauss rig friction test input parameters for heavy duty vehicles respectively. Table 4 shows the output parameter of test results.

TABLE 2 SPECIFICATIONS OF GREY CAST IRON ROTOR INERTIA WHEELS

D_r	t_r	R_f	Hardness BHN	Grey cast iron having nominal composition (wt.%) :	Heat treatment
215	10.5	95.5	163-217	C-3.5, Si-2.0, Mn- 0.8 C_r-0.3, Mo-0.35, Ni-1.1 S-0.1 P- 0.3	Soak at 450 °C for 3 hrs. Followed by furnace cooling.

TABLE 3 KRAUSS RIG FRICTION TEST INPUT PARAMETERS – HEAVY DUTY VEHICLES

Applications	Test specifications	Test parameter						
	Test code: ECR R-90	K.E. kgfm	N rpm	p_b, MPa	A_{pad} cm^2	M kgm	t_b sec	t_i sec
Heavy duty test	AN700/ADB-0130	6000	660	1.3	29.1	50	5	10

TABLE 4 KRAUSS RIG FRICTION TEST OUTPUT PARAMETERS – HEAVY DUTY VEHICLES

TEST CODE: AN700/ADB130-ECR R-90

p	Tem. rise		Friction test report				Wear test report					
							Thick., mm		Wt., gm		Avg. wear	
	T_{min}, ^0C	T_{max}, ^0C	μ_{min}	μ_{max}	$\Delta\mu = \mu_{max} - \mu_{min}$	$\mu_{avg.}$	Pad1	Pad2	Pad1	Pad2	Thick., mm	Wt., gm
FAl01	40	200	0.26	0.46	0.26	0.36	0.30	0.36	2.9	2.5	0.33	2.7
FAl02	40	200	0.27	0.49	0.22	0.38	0.33	0.37	3.0	3.2	0.35	3.1
FR*	40	600	0.31	0.48	0.17	0.42	0.29	0.32	3.1	3.2	0.31	3.2

* Commercially available resin based material was tested on AN700/ADB130-ECR R-90

Symbols: Symbols used in tests are K.E. - kinetic energy, p_b- brake pressure, M-brake torque, A_{pad}-pad area, t_b-brake applied time t_i- interval between successive braking, μ-coefficient of friction and T-temperature rise.

Results

Tribo-test output parameters in 50 nos. of braking cycle of Al based composites namely FAl01 and FAl02 are summarized in Table 4. It provides tribo-performances in terms of maximum temperature rise at contact surface of brake pad and disc, max., min. and avg. coefficient of friction, fluctuation in coefficient of friction, wear in terms of weight loss (gm) and pad thickness (mm).

1) Wear (gm): It is inferred from fig.1 that wear of composite FAl01 is times lower in comparison to resin based composite FR* at applied brake pressure 1.3 MPa. in 50 nos. of braking cycle. It is observed that the wear for composites FAl01 and FAl02 is 1.2 and 1.03 times lower respectively in comparison to the wear of commercially used resin based composites FR*. It may be concluded that the composite FAl01, which incorporates more SiC (wt. %) has low wear in comparison to wear of composite FAl02.

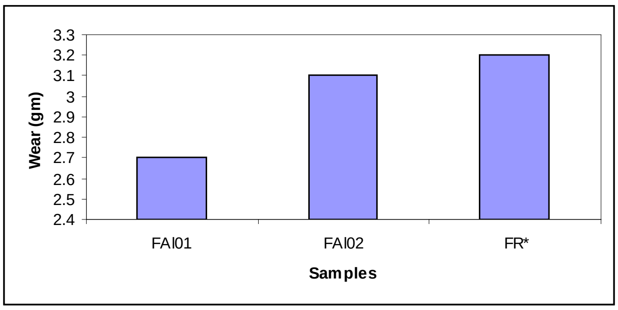

FIG.1

2) Wear (mm): The wear for composites FAl02 is slightly higher in comparison to wear of composite FAl01 (Table 4). The wear of developed Al based composites is higher in comparison to wear of commercially used resin based brake pad materials. It is also observed that the wear for composites FAl02 is slightly higher in comparison to wear of composite FAl01. It may be concluded that thickness variation depends upon type of ingredient addition in matrix as well as the density difference.

3) Avg. coefficient of friction: Figure 2 shows the effect of ingredients on avg. coefficient of developed Al powder based brake pad at applied brake pressure 1.3 MPa and speed= 660 rpm in 50 nos. of braking cycle. From figure, it is observed that avg. coefficient of friction for developed Al based composites is lower in comparison to coefficient of friction of commercially used resin based composites FR*. For composites FAl01 and FAl02, it is 1.2 and 1.1 times lower respectively than the coefficient of friction of resin based composite FR*. It varies corresponding to chemistries of brake pads materials. It is noticed that coefficient of friction for both the tested composites are lie in automotive standard industries range 0.33 to 0.45 [8]. This range is shown in fig .2 by shaded region.

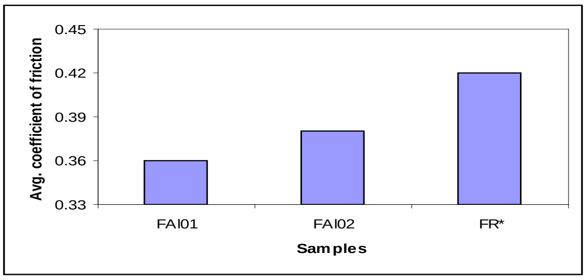

FIG.2

4) Temperature rise (^{0}C): From figure 3, it is observed that max. Temperature rise range for developed Al based composites is constant. For Al based composites, it is about 200 ^{0}C whereas for resin based composite, it is about 600^{0}C. It inferred that temperature rise for resin based friction material is three times more than that of Al based friction material.

5) Fluctuation in coefficient of friction: The fluctuation in coefficient of friction ($\Delta\mu$) for developed Al based composites is higher in comparison to coefficient of friction of commercially used resin based composites FR* (Table 4). For Al based composites FAl01 and FAl02, it is 1.5 and 1.3 times higher than that of resin based composite FR*. The fluctuation in coefficient of friction for developed Al based composite FAl02 is 1.2 times lower in comparison to fluctuation in coefficient of friction of developed Al based composite FAl01. The lower fluctuation in coefficient of friction of the developed Al based composite FAl02 in comparison to developed Al based composite FAl01 shows the role of adjustment of wt.% of ingredient namely graphite with SiC in matrix.

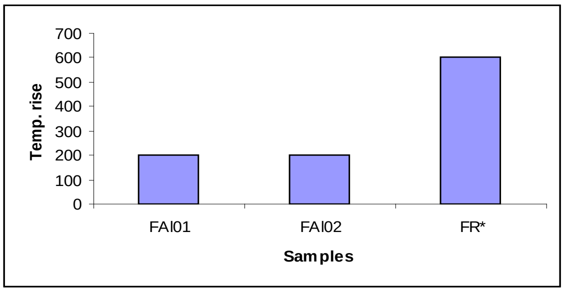

FIG.3

Micrographs of fracture surface of brake pad materials

The microstructure of fracture surfaces for developed Al powder based composites namely FAl01 and FAl02 are studied in three regions namely back plate materials, friction materials and at interface using scanning electron microscope of 200X (fig. 4). The regions like B for back plate materials, F for friction materials and I for interface are shown in figs. 2 (i) and figs. 2 (ii).

The micrographs of back plate material of composites show the uniform distribution of SiC (fine-50 μm) with matrix (Al powder-100μm). In regions-F, it is clear that SiC (coarse) is also uniformly distributed with matrix of composites. No clustering and agglomeration of ingredients at interface are observed. Interface is clearly defined for both developed composites.

Discussions

It is observed from test results that wear resistance is improved with stabilized coefficient of friction by using of better combination of frictional additives namely SiC, solid lubricants like graphite and antimony tri sulphide and other ingredients namely zinc and barium sulphate. The addition of SiC improves the hardness of composites, thereby wear resistance is improved, whereas solid lubricants is

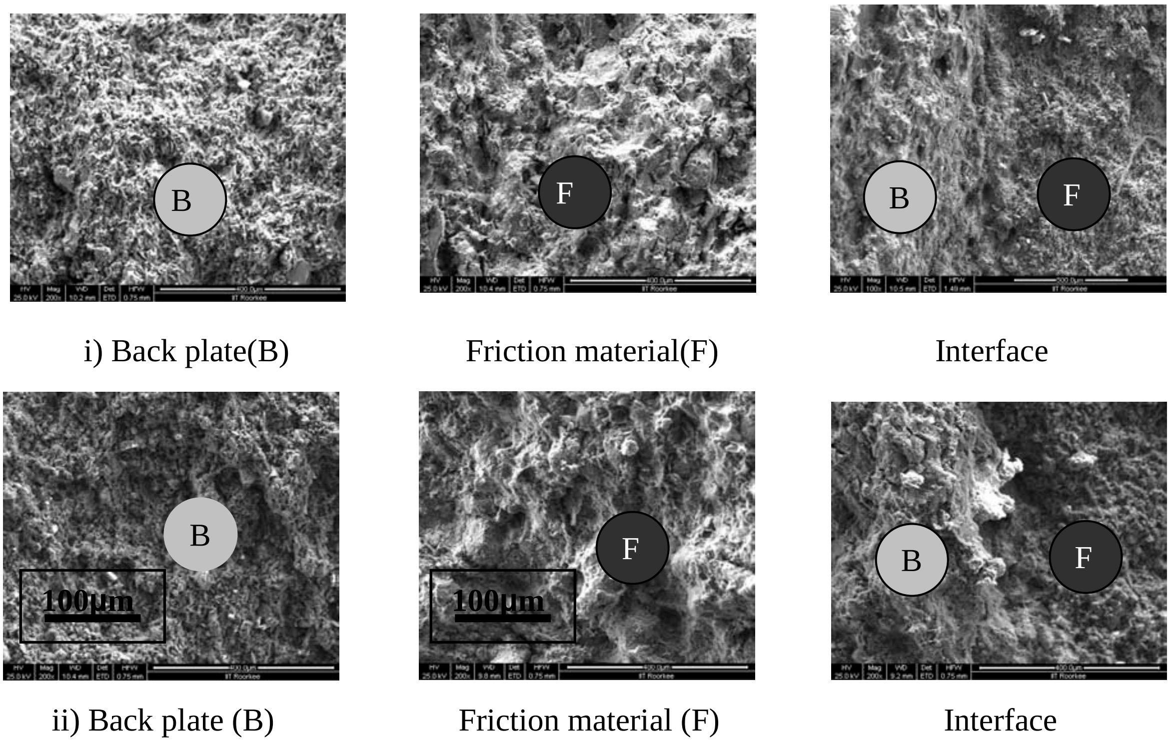

FIG. 4 MICROGRAPHS OF FRACTURE SURFACE OF BRAKE PAD MATERIALS I) FAL01 II) FAL02 (200X)

responsible for both low wear and stable coefficient of friction [11, 12]. It is also noticed that wear resistance is improved when addition of wt. % of SiC in composites lies in a range from 10 to 15 %. Relative adjustment of graphite and antimony tri sulphide with matrix materials play very crucial role. Better combination is about 9 wt. % of graphite and 3 wt. % of antimony tri sulphide (9G3S) [10].

The fluctuation in a coefficient of friction of brake pad as a function of applied pressure and solid lubricants is a very important issue because drivers expect the same level of friction force at various braking conditions. The fluctuation in the COF is also related to break phenomena such as noise, anti-fade, and vibration [9]. The COF of friction material often varies as the sliding speed changes, and this amount of COF variation is highly dependent on ingredients in the friction material. When the COF increases as the sliding speed decreases, the friction force increases at the end of the stop, and can then cause an unpleasant forward jerking at the end of a stop. The increase of the COF at the end of a stop is called anti-fade and is often concomitant with noise and judder [9].

Conclusions

1) Wear loss of Al powder based brake pads is lower than resin based brake pad.
2) Coefficient of friction is lower in comparison to resin based brake pad material whereas it.
3) Temperature rise in developed Al based composites is three times lower in comparison to temperature rise in resin based brake pad material.
4) Fluctuation in coefficient of friction is slightly higher in comparison to resin based brake pad material.

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